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# Mapping Habitat and Deforestation in WWF Elephant Priority Landscapes

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## Introduction

Habitat loss and the resulting human-elephant conflict (HEC) are threatening the survival of wild Asian elephant populations (Sukumar 1989, 2003; Fernando *et al*. 2005, Fernando & Leimgruber 2011). The geographic range of the Asian elephant has declined as much as 75% over the last century (Fernando & Leimgruber 2011). The two major causes for the loss of Asian elephant habitat are: a) expansion of subsistence agriculture and b) broad-scale conversion of elephant habitats into industrial plantations and agriculture such as sugar cane, rubber, and oil palm (Flint 1994; Leimgruber *et al*. 2003; Sodhi *et al*. 2004; Koh & Wilcove 2008; Uryu *et al*. 2008). Habitat loss patterns vary significantly across the 13 Asian elephant range countries and habitat losses can be catastrophic both locally and regionally (Santiapillai & Jackson 1990; Leimgruber *et al*. 2003; Fernando & Leimgruber 2011). Yet, baseline data against which to evaluate habitat loss has not been compiled for most of this geographic range and little information on elephant habitat, land cover and habitat loss is available for systematic assessments, monitoring, and conservation planning.

In an effort to address this challenge the WWF Asian Rhino and Elephant Action Strategy Programme (AREAS) and the Smithsonian Conservation Biology Institute (SCBI) worked together to compile available data for WWF priority landscapes. AREAS moves beyond individual protected areas by focusing on WWF landscapes that have been prioritized based on their importance to Asian rhinos and Asian elephants. Within these priority landscapes AREAS objectives are to assess social, economic, and biological components of rhino and elephant conservation in order to secure essential core habitat and corridors across Asia. AREAS and SCBI partners collaborated to compile and analyze existing land cover and threat databases for Asian elephants for the WWF landscapes that were prioritized specifically for elephants. By standardizing land cover, land cover change, and HEC records provided by AREAS partners, we have synthesized the best-available data for all WWF landscapes important for Asian elephants.

Bringing together diverse land cover data sets often results in inconsistencies between maps covering the same area. There are many reasons for these discrepancies (Leimgruber *et al*. 2011), for example, different analysts often start out with different definitions for their various land cover classes. This is particularly a problem in transitional classes such as degraded forest, ecotones, or areas such as plantations, which could be considered forest but do not have many of the ecological characteristics of natural forests. Variation in data sources is another cause of discrepancies, for example, satellite data may differ in year collected, phenological time period, spatial resolution, and spectral resolution. Integrating best available land cover data from various sources to cover a broader region may provide better accuracy than using a global dataset already covering the area of interest,

though it does require more effort to resolve differences.

We evaluated and compared the performance of five commonly used global land cover data sets with Tiger Land Cover Data (TLCD), a map developed for Tiger Conservation Landscapes assessment (Dinerstein *et al*. 2006), and found TLCD was most accurate for our areas of interest. We updated the TLCD by including newly available fine resolution data from throughout the WWF AREAS priority landscapes. Based on this data we identified the landscapes where elephants are facing the greatest threats, and where conservation efforts may be most effective. We found that different types of conservation efforts, such as expanding protection status to places falling outside protected areas, increasing enforcement of areas already protected, or working with communities to mitigate conflicts and impacts, are needed to varying degrees in different landscapes.

## Methods

WWF has 11 landscapes for Asian elephants that were prioritized because they support globally important elephant populations, have the potential for connectivity, and represent the range of ecological habitats where elephants still occur. These areas range from a single large protected area and surrounding area to transboundary landscapes that include several protected areas. Within each landscape WWF has an on-the-ground presence working on elephant monitoring and conservation. WWF landscapes are found in 7 of the 13 Asian elephant range countries and cover one-third, or 176,897 km$^2$ of the 526,083 km$^2$ of the confirmed geographic range (Hedges *et al*. 2009; Fig. 1). Working with WWF partners, we collated moderate-resolution (30 m) land cover for 94% of the WWF landscape areas for elephants (Table 1). For landscapes lacking detailed coverage, range country experts examined five commonly-used global land cover products (Table 2) and a land cover map developed by for the Tiger Conservation Landscapes report, which was an effort by WWF, the Wildlife Conservation Society, and the SCBI to consolidate and analyze the best and most recent spatial data on tiger status and distribution, land cover throughout their range, and threats in order to prioritize conservation efforts (Dinerstein *et al*. 2006). This Tiger Land

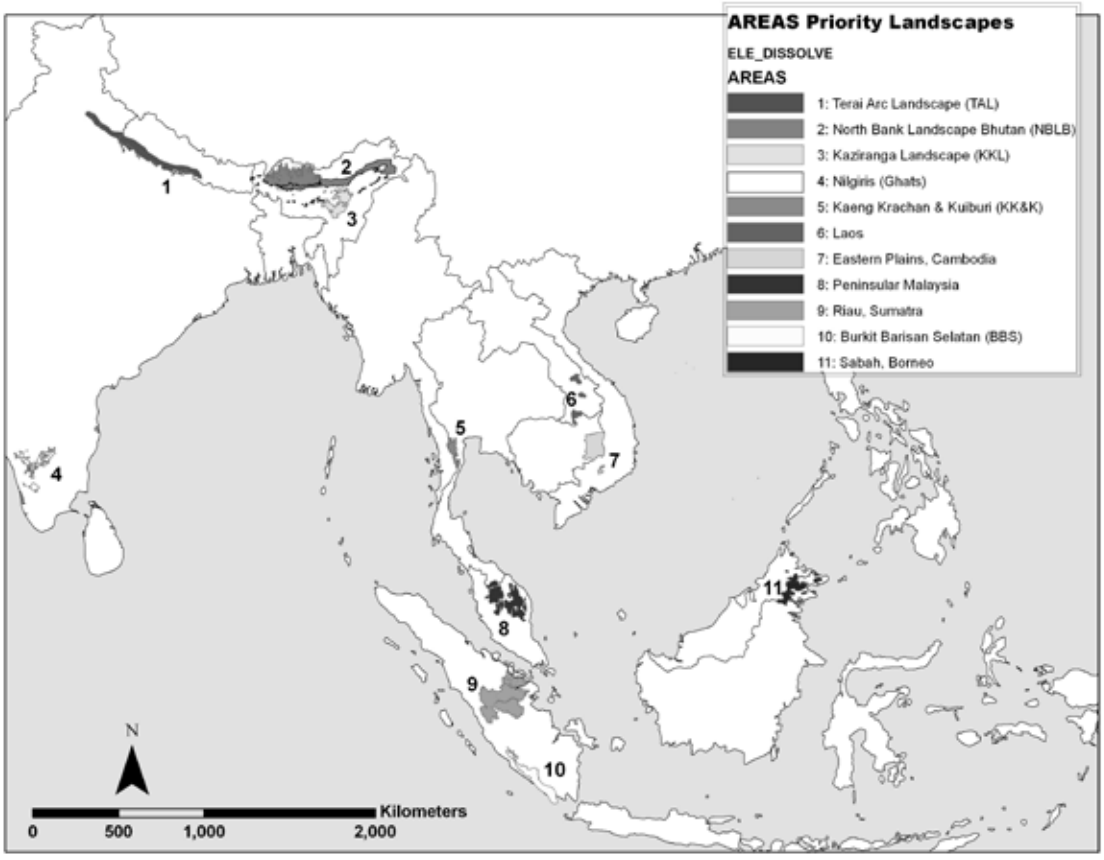


**Figure 1.** WWF priority landscapes for Asian elephants.

Cover Data (TCLD) was created by integrating the finest resolution land cover data available in 2004 for different tiger range areas into a regional map (Leimgruber & Songer 2006). Based on rankings from workshop experts, no regional or global data set performed well in all priority landscapes, however the TLCD had the highest accuracy scores overall and was chosen to fill data holes where detailed local land cover information was not available. Range country experts then standardized their land cover maps into eight general categories identified by consensus (water bodies, closed forest, open forest, grassland, plantation, agriculture, developed, open/barren land).

Land cover change analyses were provided for all or part of seven landscapes (Terai Arc Landscape, North Bank Landscape and Bhutan, Kaziranga, Laos, Eastern Plains, Riau, Bukit Barison Selatan). Land cover change data sets covered various time periods and a series of assessments through time were available for some landscapes. To standardize these various data we calculated the overall annual conversion rate for each area over the full time period. Land cover conversion was defined as changing from a natural area (closed forest, open forest, or grassland) to a non-natural cover (plantation, agriculture, developed). For the island of Sumatra we had a series of land cover change assessments for the whole island, which were used for the Bukit Barisan Selatan landscape, and a separate series of land cover change assessments specifically for Riau.

Following a similar methodology as used for the Tiger Conservation Landscapes assessment (Dinerstein *et al*. 2006), we used the Human Impact Index (HII, Sanderson *et al*. 2002) as a measure of human influence in WWF landscapes. The HII measures the ecological footprint left by humans and assigns a value from 1 to 72 to each 1 km$^2$ pixel, with pixels registering at 72 experiencing the highest degree of human impact. The index is based on four types of data: human population density, land cover change, accessibility (roads, railways, rivers, and coastline), and electrical power infrastructure systems (Sanderson *et al*. 2002). During the Tiger Conservation Landscapes assessment, a HII value of 16 was identified as a critical threshold based on analysis of tiger presences and absences (Forrest *et al*. 2006). Comparing the mean HII values for points with tigers and without tigers we found there is a transition around HII 16; below this level it is more likely than would be

**Table 1.** Summaries of land cover, human impact and protected area coverage for each WWF landscape prioritized for Asian elephants.

| WWF AREAS Landscapes | Total Area | Natural Area[1] | | Area Protected | | Area >16 HII[2] | | Land cover WWF | |
|---|---|---|---|---|---|---|---|---|---|
| | km$^2$ | km$^2$ | % | km$^2$ | % | km$^2$ | % | km$^2$ | % |
| TAL, India & Nepal | 19,447 | 14,013 | 72 | 7,365 | 24 | 14,002 | 72 | 18,748 | 96 |
| NBL&B, India | 25,601 | 20,986 | 82 | 10,632 | 20 | 14,481 | 43 | 18,006 | 70 |
| Kaziranga Landscape, India | 13,364 | 11,953 | 89 | 630 | 5 | 10,861 | 19 | 13,036 | 98 |
| Nilgiris (Ghats), India | 11,641 | 9,834 | 84 | 7,226 | 28 | 5,895 | 49 | 9,036 | 77 |
| KK&K, Thailand | 4,951 | 4,789 | 97 | 4,244 | 86 | 49 | 1 | 4,871 | 99 |
| Laos | 5,606 | 5,253 | 94 | 4,845 | 86 | 3,592 | 64 | 5,606 | 100 |
| Eastern Plains, Cambodia | 15,148 | 13,740 | 91 | 9,776 | 65 | 757 | 5 | 15,148 | 100 |
| Peninsular Malaysia | 25,859 | 25,583 | 99 | 7,467 | 29 | 1,552 | 6 | 25,859 | 100 |
| Sabah, Borneo, Malaysia | 14,096 | 13,543 | 96 | 2,897 | 19 | 2,511 | 17 | 14,098 | 100 |
| Riau, Sumatra, Indonesia | 26,673 | 13,904 | 52 | 12,976 | 28 | 11,203 | 42 | 26,674 | 100 |
| BBS, Sumatra, Indonesia | 14,511 | 8,246 | 57 | 6,657 | 46 | 5,979 | 37 | 14,652 | 100 |
| Total | 176,897 | 41,844 | 80 | 74,715 | 42 | 70,882 | 40 | 165,734 | 94 |

[1] This area was calculated based on the consolidated data from WWF AREAS partners and using Tiger Land Cover Data for areas where AREAS land cover data was not available. Classes that we considered natural were closed forest, open forest, grasslands, or water bodies.

[2] Human Impact Index (HII) data is a precursor to the Human Footprint dataset (Sanderson *et al*. 2002). It incorporates human population density, land use, accessibility, and power infrastructure. We calculated how much area within each of priority landscapes measured 16 or above on the HII scale, since this threshold has been identified as incompatible with tiger presence (Forrest *et al*. 2006).

expected by random for tigers to be present and above this level it is less likely than expected by random to find them. Both tigers and elephants are large mammals that are at risk of coming into conflict with humans as human presence and impact increase and we used the tiger threshold as an indicator of human impact in our threat assessment for Asian elephants.

## Results

WWF landscapes for Asian elephants are characterized primarily by natural habitat (Table 1), including closed forest (63%) and open forest (15%) interspersed with grasslands, open/barren land and water bodies (all 3 combined covering 5%; Table 3). The remaining 16% of the area in WWF landscapes are covered by agriculture (10%) and plantations (6%). Land cover composition, however, varies greatly among different landscapes. For example, the amount of natural land cover ranges from 99% in Peninsular Malaysia to only 52% in Riau, Sumatra. Land devoted to agriculture, the main reason for human-elephant conflict, ranges from <1% of area in the Malaysian landscapes (Peninsular Malaysia and Sabah), up to 34% in the Bukit Barisan Selatan landscape (BBS). Plantations made up ≤4% of the land cover in all landscapes except Riau, which has more than a third of the area in use for plantations.

Only 38% of WWF elephant landscape area falls within protected areas (IUCN Categories I-VI; UNEP-WCMC 2009). Within the protected areas 9% of the land cover is classified as either agriculture or plantation (Table 4). In all priority landscapes, forests (either closed or open) make up the largest percentage of land cover. The Kaeng Krachan & Kuiburi (KK&K) and Laos landscapes have the greatest percentage of the area protected with 86% (4244 km$^2$ and 4845 km$^2$ respectively), however, Riau has the largest amount with nearly 13,000 km$^2$ falling under protected status. Despite the protected status, some landscapes, such as the Nilgiris and BBS, have high percentages of agriculture within their protected areas – with 17% and 19% respectively.

Land cover change analyses show annual conversion rates within WWF landscapes ranging from 0.01% in Bhutan (1991-2005) up to

**Table 2.** Global land cover data sets, their sources, time periods, spatial resolution (SR), imagery used and average ranking based on evaluations by regional experts.

| Classification[1] | Source | Time Period | SR | Imagery Used[2] | Ranking[3] |
|---|---|---|---|---|---|
| IGBP Discover | USGS EROS DAAC <http://edc.usgs.gov/products/landcover/glcc.html> | 1992 –1993 | 1 km$^2$ | AVHRR | 4.0 |
| GLC 2000 | European Commission's JRC <http://www-gvm.jrc.it/glc2000/> | 1999 –2000 | 1 km$^2$ | SPOT 4 VEGETATION | 2.7 |
| Glob-cover | European Space Agency <http://ionia1.esrin.esa.int/> | 2004 – 2006 | 300 m$^2$ | ENVISAT-MERIS | 3.3 |
| FAO- FRA | FAO-FRA <http://www.fao.org/forestry/fra/en/> | 2000 | 1 km$^2$ | AVHRR | 3.9 |
| MLCC | Boston University <http://edcimswww.cr.usgs.gov/pub/imswelcome/> | 2000 –2001 | 1 km$^2$ | MODIS | 4.5 |
| TLCD | Save the Tiger Fund <http://www.savethetigerfund.org> | various, 1997-2004 | 1 km$^2$ | various, compilation of 30 m – 1 km | 2.4 |

[1] IGBP DISCover = International Geosphere-Biosphere Programme (IGBP) DISCover (Belward *et al*. 1999; Loveland *et al*. 2000); FAO-FRA = Food and Agriculture Organization-Forest Resources Assessment; GLC2000 = Global Land Cover 2000 (Bartholome and Belward 2005; Roy *et al*. 2003); MLCC = MODIS/Terra Land Cover Classification (Strahler *et al*. 1999; Friedl *et al*. 2002); TLCD = Tiger Land Cover Data (Leimgruber & Songer 2006).

[2] AVHRR = Advanced Very High Resolution Radiometer; SPOT = Satellite Pour l'Observation; MODIS = MODerate Resolution Imaging Spectroradiometer; ENVISAT-MERIS = ENVISAT's Medium resolution Imaging Spectrometer Instrument.

[3] Overall rank averaged from scores assessed by experts for 13 regions across the elephant range. The experts ranked the data sets by assessing how well the maps represented the regional areas where they have firsthand knowledge and assigning a rank of 1 to 6, 1 being best and 6 worst.

**Table 3.** Amount (km$^2$) and percent coverage for each type of land cover found in priority landscapes, based on consolidated WWF Asian Rhino and Elephant Action Strategy data and the TLCD.

| WWF AREAS Landscapes | Water-body | Closed Forest | Open Forest | Grass-land | Plan-tation | Agri-culture | Developed | Open/ Barren |
|---|---|---|---|---|---|---|---|---|
| TAL, India & Nepal | 268 (1%) | 7,779 (40%) | 4,990 (26%) | 976 (5%) | - | 5,137 (26%) | - | 297 (2%) |
| NBL&B, India | 393 (2%) | 14,776 (58%) | 5,595 (22%) | 222 (1%) | 149 (1%) | 3,328 (13%) | 7 (0%) | 1,131 (4%) |
| Kaziranga Landscape, India | 592 (4%) | 8,462 (63%) | 2,589 (19%) | 310 (2%) | 426 (3%) | 680 (5%) | 4 (0%) | 301 (2%) |
| Nilgris (Ghats), India | 55 (0%) | 9,045 (78%) | 734 (6%) | - | - | 1,324 (11%) | - | 483 (4%) |
| KK&K, Thailand | 29 (1%) | 4,743 (96%) | 17 (0%) | - | - | 162 (3%) | - | - |
| Laos | 31 (1%) | 2,882 (51%) | 2,284 (41%) | 56 (1%) | - | 268 (5%) | - | 85 (2%) |
| Eastern Plains, Cambodia | 48 (0%) | 5,885 (39%) | 7,734 (51%) | 73 (0%) | 352 (2%) | 1,056 (7%) | - | - |
| Peninsular Malaysia | 520 (2%) | 25,060 (97%) | - | 3 (0%) | 258 (1%) | 7 (0%) | 11 (0%) | - |
| Sabah, Borneo, Malaysia | 3 (0%) | 12,106 (86%) | 1,416 (10%) | 18 (0%) | 541 (4%) | 12 (0%) | - | - |
| Riau, Sumatra, Indonesia | 62 (0%) | 11,161 (42%) | 2,382 (9%) | 299 (1%) | 9,517 (36%) | 1,232 (5%) | 269 (1%) | 1,751 (7%) |
| BBS, Sumatra, Indonesia | 126 (1%) | 7,793 (54%) | 250 (2%) | 77 (1%) | 500 (3%) | 4,895 (34%) | 53 (0%) | 817 (6%) |
| Total | 2,127 (1%) | 109,692 (62%) | 27,991 (16%) | 2,034 (1%) | 11,743 (7%) | 18,101 (10%) | 344 (0%) | 4,865 (3%) |

1.25 % in Riau (1982-2007), the latter represents near catastrophic habitat loss of over 8,000 km$^2$ lost since 1982 (Table 5). For landscapes with land cover change data, only the Kaziranga Landscape (0.18%), 3 districts in Nepal (0.03%), and the country of Bhutan (0.01%) had annual conversion rates below the global average of 0.2%.

Over 40% of WWF landscape area falls at 16 or above on the HII (Table 1). The most impacted landscape is the Terai Arc Landscape (TAL) with 72% (14,002 km$^2$) of the area experiencing high levels of human influence. Conversely, the KK&K, the Eastern Plains and the Peninsular Malaysia landscapes all have very low levels of human impact at 6% or less of the total area greater than HII 16 within each landscape.

## Discussion

Compiling the data from across the region allowed us to evaluate each landscape individually and compare across landscapes. We identified a few large priority landscapes with substantial amounts of natural area remaining. Peninsular Malaysia and the NBL&B have more than 20,000 km$^2$ natural area remaining, though less than a third of the landscape areas are protected. The Eastern Plains have nearly 14,000 km$^2$ in remaining natural area but with a higher proportion of it protected, giving this landscape an amount of protected area similar to that of the NBL&B, and more than in Peninsular Malaysia. Based on levels of protection, the Peninsular Malaysia, NBL&B, and the Eastern Plains landscapes can be considered strongholds that are relatively safe, though there are still large areas available that could benefit from protected status in each of these landscapes. The NBL&B and the Eastern Plains have annual conversion rates over 0.5%, more than twice the global average, and the NBL&B has 40% of the area showing higher levels of human impact. The Eastern Plains landscape stands out by having a lot of protected, natural area yet still shows evidence of human impact. At this point it is surrounded almost completely by forest, either open or

**Table 4.** Amount (km$^2$) and percent coverage for each type of land cover found within protected areas for priority landscapes, based on consolidated WWF Asian Rhino and Elephant Action Strategy data and the Tiger Land Cover Data.

| WWF AREAS Landscapes | Water-body | Closed Forest | Open Forest | Grass-land | Plan-tation | Agri-culture | Developed | Open/ Barren |
|---|---|---|---|---|---|---|---|---|
| TAL, India | 170 (3%) | 2,687 (44%) | 2,001 (33%) | 518 (8%) | - | 642 (10%) | - | 124 (2%) |
| NBL&B, India | 70 (1%) | 2,765 (59%) | 1,209 (26%) | 48 (1%) | 6 (0%) | 390 (8%) | - | 203 (4%) |
| Kaziranga Landscape, India | 40 (6%) | 361 (57%) | 59 (9%) | 143 (23%) | 2 (0%) | 6 (1%) | - | 19 (3%) |
| Nilgiris (Ghats), India | 39 (1%) | 3644 (73%) | 264 (5%) | - | - | 844 (17%) | - | 168 (3%) |
| KK&K, Thailand | 23 (1%) | 4129 (87%) | 8 (0%) | - | - | 84 (2%) | - | - |
| Laos | 30 (1%) | 2,569 (53%) | 2,032 (42%) | 56 (1%) | - | 77 (2%) | - | 81 (2%) |
| Eastern Plains, Cambodia | 37 (0%) | 3,570 (37%) | 5,432 (56%) | 47 (0%) | 101 (1%) | 589 (6%) | - | - |
| Peninsular Malaysia | 280 (4%) | 7163 (96%) | - | - | 24 (0%) | - | - | - |
| Sabah, Borneo, Malaysia | - | 2,445 (95%) | 50 (2%) | - | 67 (3%) | 1 (0%) | - | - |
| Riau, Sumatra, Indonesia | 3 (0%) | 5,209 (72%) | 415 (6%) | 64 (1%) | 1,039 (14%) | 235 (3%) | 11 (0%) | 288 (4%) |
| BBS, Sumatra, Indonesia | 15 (0%) | 4,586 (69%) | 237 (4%) | 67 (1%) | 291 (4%) | 1,277 (19%) | 2 (0%) | 182 (3%) |
| Total | 707 (1%) | 39,128 (66%) | 11,707 (20%) | 943 (2%) | 1,530 (3%) | 4,145 (7%) | 13 (0%) | 1,065 (2%) |

closed, allowing for the possible creation of a suitable buffer zone before further encroachment by plantations and agriculture.

Other large landscapes including the TAL, the Kaziranga, the Nilgiris, the KK&K, Riau, BBS, and Sabah have between 10-14,000 km$^2$ of natural area remaining, however, except for the BBS each landscape has less than a third of their area currently protected. These areas have great potential for expansion of protected coverage, particularly in areas that are still natural and relatively intact. The Kaziranga landscape, perhaps one of the most biologically diverse areas in India supporting elephants, tigers and rhinoceroses, has only 630 km$^2$ protected and is losing forest at a rate of 0.18% (just below the global average). The TAL and the Nilgiris are also important biodiversity strongholds in India and are in urgent need of expanded protection, with half or more of the area highly impacted by humans. In these landscapes where humans and wildlife interface closely the threat of conflict with wildlife and increased pressure on the natural resources grows as human populations steadily increase.

The landscapes of Sumatra are in need of urgent action to slow the rapid conversion for agriculture, particularly for plantations. These landscapes have some of the highest conversion rates and levels of human impact. The Riau landscape is of particular concern as it had by far the greatest amount of forest loss and highest annual rate of conversion of all the regions that provided land cover conversion data, likely due to conversion of forest to plantations which make up a quarter of the Riau land cover. Only half of the land cover is natural area and less than a third of the landscape is protected, making this a significant threat hotspot. The BBS landscape faces similar challenges with nearly 40% agriculture or plantation cover and high levels of human impact and conversion. The annual conversion rate is about half of the rate found in Riau, but is still much higher than the global

average, and some of the loss is occurring within protected areas. In this case, rather than pushing for expanded protected area the priority should be to slow conversion through better enforcement of protected status and other mitigation strategies.

The two smallest areas, the KK&K and Laos landscapes, maintain high percentages of natural area remaining and area protected. While the KK&K shows little evidence of human impact, Laos shows greater than 60% of the area with a HII of greater than 16. This area is under high pressure for subsistence collection of non-timber forest products and urgently needs efforts balancing use and conservation, especially since the area is already small and does not have a lot to lose. Along with the TAL, the Laos landscape is highly fragmented should be explored for opportunities for community conservation and reforestation efforts to help restore connectivity.

Land cover change analyses show the need for immediate action in the priority landscapes with higher conversion rates, such as the Riau, BBS, NBL&B, and Eastern Plains landscapes – all with well over twice the average annual deforestation rate. These impacts are likely ongoing and need closer investigation and strategies for reducing rates of loss. Riau and BBS have a series of land cover data for various periods covering 20 years or more and could be analyzed for land cover change dynamics over recent decades. Land cover change analysis is needed for areas that are potentially hotspots of change with low levels of protection and high HII scores; such is the case in several of the Indian landscapes including the TAL, where there is only land cover change data for three districts, the Kaziranga, and the Ghats.

Our evaluation of land cover by regional experts was a simple process, however, it is rare that experts with on-the-ground knowledge assess accuracy of land cover maps – despite the fact that these maps are used extensively by researchers, managers, and policy makers for anything from basic research on animal ecology to assessments for climate change legislation. WWF has an extensive network of field and GIS experts located in major biodiversity hotspots; this network could be actualized to provide real world data for evaluating and improving the land cover maps we rely on for assessing the status of key charismatic megafauna such as elephants, tigers, and rhinos as well as for other research and conservation efforts. As key habitats are coming under increasing pressure it is critical to collect consistent and more comprehensive information for critical areas such as the WWF landscapes and to use it effectively in conservation planning.

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**Table 5.** Area of forest lost, overall annual conversion rate, and time period analyzed within WWF landscapes for Asian elephants.

| Region | Area lost in km$^2$ | Area lost in % | Annual Conversion Rate | Time Period |
|---|---|---|---|---|
| Riau, Sumatra | 8335 | 31.3 | 1.25% | 1982 - 2007 |
| BBS, Sumatra | 2140 | 14.8 | 0.59% | 1982 - 2007 |
| North Bank (part of NBL&B) | 1703 | 6.6 | 0.51% | 1991 - 2005 |
| Eastern Plains, Cambodia | 751 | 5.5 | 0.50% | 1996 - 2006 |
| Laos | 309 | 6.0 | 0.33% | 1992 - 2002 |
| Kaziranga Landscape | 333 | 2.5 | 0.18% | 1991 - 2005 |
| Nepal (part of TAL)* | 28 | 0.5 | 0.03% | 1990 - 2006 |
| Bhutan (part of NBL&B)** | 23 | 0.2 | 0.01% | 1991 - 2005 |

*Data covers 3 districts (Mahendra Nagar, Bardiya, Jhapa) in Nepal.

**Data covers about half of the Bhutan portion of the NBL&B Landscape.

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